SECTIONED CONDUCTOR AND RELATED METHODS FOR ACCOMMODATING STRESS AND AVOIDING INTERNAL DEFORMATIONS IN POWER GENERATOR

Field of The Invention

The field of the invention relates to electrical conductors and, more specifically, electrical conductors in power generation systems subject to stress forces.

Background of the Invention

Conventional power generators generate electrical energy by means of induction. Such generators employ a stator core along with a rotor shaft having rotor coils associated therewith to rotate within the stator core in order to convert mechanical energy into electrical energy. Within the rotor shaft, extending axially relative to the lengthwise extent of the rotor, a pair of axial leads carry electrical current. To electrically connect an axial lead to the rotor coils associated with the rotor shaft, a radial stud often extends from the surface of the rotor shaft into the shaft to connect to the axial lead. A heavy conductor, usually positioned within a slot formed in the rotor shaft, electrically connects the axial lead to the rotor coils (usually the inner coil, which itself is connected electrically to the other coils).

These heavy conductors are often referred to as "J-leads" because their shape resembles that of a "J" lying on its side. As illustrated in FIG. 1, the conventional J-lead **12** comprises a straight axial portion **14** connected

at one end to the radial stud **32'** and extending in an axial direction relative to the rotor shaft **24'**, and, at the opposite end of the straight portion, a radial portion **16** that extends outward in a radial direction to connect to the rotor coil **28'**.

The J-lead conductor **12** often is subject to stress forces stemming from several distinct sources. For example, as the rotor shaft spins within the stator core, centrifugal forces are generated. The rotor coils are positioned within axial slots **34'** extending along the length of the rotor shaft **24'** and retained therein by a retaining ring **30'** surrounding a portion of the rotor shaft **24'**. Centrifugal force deflects the retaining ring **30'** and tends to pull the rotor coils away from the rotor shaft **24'** as it rotates at an extremely rapid speed. The J-lead **12** connected to the inner rotor coil **28'** correspondingly experiences a stress force acting in a radial direction relative to the rotor shaft **24'** and tending to pull the J-lead **12** radially away from the rotor shaft **24'**.

The J-lead also experiences stress forces due to thermal expansions acting in an axial direction relative to the lengthwise extent of the rotor shaft. Because the J-lead and the rotor coils are conductors, electrons move at constant average "drift" velocity through the lead and coils experiencing continual collisions with the atoms of the crystalline structures of the lead and coils. These collisions, of course, generate heat and cause thermal expansions of the J-lead **12** and the rotor coils. Because one end of the elongate portion **14** of the J-lead is fixedly connected to the radial stud, thermal expansion of the J-lead often is axially biased, causing the end opposite to the one connected to the radial stud **32'** to move farther away from the radial stud **32'**. At the same

time, thermal expansion of the rotor coil **28'** generates a stress force in the opposite direction acting on that portion **16** of the J-lead that extends outwardly in a radial direction from the rotor shaft **24'** and attaches to the coil. As the coil expands, the portion of the J-lead that is attached to the coil is pushed toward the radial stud **32'**.

Thus, the net effect of these thermal expansions is that as one part of the J-lead **12** is forced away from the radial stud **32**, another part is forced toward the radial stud **32'**. The first force is due to a force acting on a first portion of the J-lead **12** positioned close to the rotor shaft, the second force is on a second portion of the J-lead **12** above the first portion and connected to the rotor coil. The result is that medial portions between the first and second portions of the J-lead are subjected to forces causing internal deformation.

In addition to the centrifugal forces due to rotation of the rotor shaft **24'** and the deforming forces due to thermal expansion, the J-lead **12** is also subjected to a variety of other forces including those stemming from vibrations within the generator and accentuated by possible pre-stress owing to the manner of installation and manufacturing variations.

In an attempt to accommodate these various forces, J-leads have conventionally been designed and manufactured to purposely permit internal deformation. Some J-leads, for example, are formed by joining in parallel several, reduced-diameter conductors or laminations. A persistent problem, however, is how to find a material that both permits the lead to flex and bend in response to stress forces and also acts as a good conductor. Copper, for example, is a good conductor, but has very poor fatigue properties. In addition, copper is difficult to form

multiple parallel conductors into a J-lead and simultaneously provide adequate mechanical support. Components that provide mechanical support and bending capability require tightly controlled tolerances in manufacturing. The parts forming the J-lead must be very carefully assembled in accordance with very complicated procedures.

Not only are these procedures costly, they are fallible no matter how rigorously performed. Firstly, it is extremely difficult to calculate all initial pre-stress factors and J-lead stress forces under different operating conditions. Secondly, it is very difficult to predict how dimensional variations and other factors will influence the stress forces on the J-lead. Indeed, despite complicated attempts to engage in finite element analysis and conduct rigorous fatigue simulations, there continue to be notable J-lead failures.

Summary of the Invention

In view of the foregoing, the present invention advantageously provides a conductor that substantially avoids internal deformation due to various stress forces on the conductor while providing a conductive path between distinct components of a generator. The substantial avoidance of internal deformation in the conductor makes the failure of the conductor considerably less likely. Specifically, reducing or eliminating entirely internal deformation accordingly reduces the probability of cracks in the conductor structure arising from stress-induced structural fatigue. Hence, a sectioned conductor of the present invention is much more reliable than devices like the conventional J-lead since the internal deformations that can cause fatigue leading to a breakdown are substantially eliminated.

Another distinct advantage of the present invention is the ease and efficiency with which a sectioned conductor according to the present inventor can be manufactured and installed. Instead of requiring intricate manufacturing steps to align and connect multiple, small-diameter conductors into a monolithic J-lead, separate pieces of the sectioned conductor are electrically joined easily and efficiently.

According to the present invention, a sectioned conductor is formed to have at least two sectioned members that remain electrically connected while being able to move relative to each other in response to stress forces. In the context of a power generator, the sectioned conductor includes at least a first sectioned member connected to a radial stud and a second sectioned member connected to at least one rotor coil to thereby provide a conductive path between the radial stud and the rotor coil. In a preferred embodiment, the second sectioned member of the conductor is adapted to respond to centrifugal forced generated by the rotation of the rotor within a stator by moving radially and independently of the remainder of the conductor as the coils and the retaining ring to which they attach move radially away from the rotor in response to the centrifugal force. Yet, as already noted sectioned members remain electrically connected even as the second sectioned member moves relative to the first.

The second sectioned member, moreover, is adapted to move axially in response to thermal expansion of the rotor coil resulting from current-induced temperature rises in the rotor coil. The second sectioned member is also free to move in substantially any direction in response to a combination of axially and radially directed forces such as those stemming from vibratory motions in the rotor.

As explained more fully herein, the present invention also encompasses related methods for reducing or eliminating stress forces in an electrical conductor. More specifically, the present invention provides a method for accommodating stress forces on an electrical connection while providing a conductive path between at least two spaced-apart electrical components within a generator. The method includes positioning a first portion of a conductor so as to electrically connect the conductor to a first component of at least two electrical components, and positioning a second portion of the conductor to electrically connect to a second component. The first and second portions of the conductor, moreover, are adapted so as to permit the second portion to move relative to the first portion in response to stress forces while remaining electrically connected to the first portion. The second portion, more specifically, moves relative to the first so as to substantially avoid internal deformation of the conductor Thus, among the other advantages, the present invention provides a method for providing and maintaining a conductive path with an electrical conductor that is substantially free of stress-induced internal deformation.

Brief Description of the Drawings

Some of the features, advantages, and benefits of the present invention having been stated, others will become apparent as the description proceeds when taken in conjunction with the accompanying drawings in which:

FIG 1 is a fragmentary perspective view of a conventional J-lead according to the prior art;

FIG. 2 is a top plan view of an apparatus according to a first embodiment of the present invention;

FIG. 3 is a fragmentary sectioned view of a sectioned conductor connected to a rotor coil and radial stud

extending into a rotor shaft according to a first embodiment of the present invention;

FIG. 4 is a perspective view of a rotor shaft and a sectioned conductor having a portion phantomed-in for clarity according to a first embodiment of the present invention;

FIG. 5A is a fragmentary perspective view of a sectioned conductor according to a first embodiment of the present invention;

FIG. 5B is a fragmentary perspective view of a sectioned conductor according to a first embodiment of the present invention;

FIG 6 is a fragmentary perspective view of an apparatus having a sectioned conductor according a first embodiment of the present invention;

FIG. 7 is an exploded fragmentary perspective view of an elastic conductor positioned in a portion of a sectioned conductor according to a first embodiment of the present invention;

FIG. 8 is an exploded fragmentary perspective view of a sectioned conductor according to a first embodiment of the present invention.

FIG. 9 is a fragmentary sectioned view of a sectioned conductor according to a first embodiment of the present invention;

FIG. 10 is a fragmentary perspective view of an apparatus having a sectioned conductor according to a second embodiment of the present invention; and

FIG. 11 is a fragmentary perspective view of an apparatus having a sectioned conductor according to a third embodiment of the present invention.

Detailed Description of Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying

drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these illustrated embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime and double prime notation, if used, indicate similar elements in alternative embodiments. Also, references similar to FIG. 1 elements described previously will use the same numbers.

FIGS. 2 through 4 illustrate an apparatus **20** adapted to accommodate stress forces and substantially avoid internal deformation while providing a conductive path in a generator such as a power generator that generates electrical power by electromagnetic induction. The apparatus **20** preferably includes a power generator stator core **22** that provides a high-permeability path for magnetism and a rotor shaft **24** positioned to rotate within the stator core **22**. The rotor shaft **24** preferably has at least one axial lead **26** extending axially within the rotor shaft **24** to provide a current path therethrough. Associated with the rotor shaft **24** is at least one rotor coil **28** which also provides a conductive path. The at least one rotor coil **28** preferably is but one of a plurality of such coils. Each of the plurality of coils preferably can be positioned within axially extending slots formed in the rotor shaft **24** and at least partially contained therein by a retaining ring **30** surrounding a portion of the rotor shaft **24**.

According to the present invention the apparatus **20** further comprises a sectioned conductor **40**. The sectioned conductor **40** connects to a radial stud **32** that extends into the rotor shaft **24** and connects to the axial lead **26**. The sectioned conductor **40** also connects to the at least one rotor coil **28** to provide a conductive path between the radial stud **32** and the at least one rotor coil **28**, thereby electrically connecting the at least one rotor coil **28** to the axial lead **26**. Preferably, the sectioned conductor **40** connects to the inner coil of a plurality of interconnected rotor coils associated with the rotor shaft **24** to thereby provide a conductive path between the at least one axial lead **26** and the plurality of interconnected rotor coils.

During operation of the power generator, the sectioned conductor **40** and the at least one rotor coil **28** undergo thermal expansions at least in part as a result of the heat generated by the electrical current carried by the sectioned conductor **40** and the at least one rotor coil **28**. Because the conductor **40** is connected to the radial stud **32**, thermal expansion of the conductor **40** is biased away from the radial stud **32**. More specifically, as the conductor undergoes thermal expansion, the end **43** of the conductor **40** opposite the radial stud **32** moves farther away from the radial stud **32**. Conversely, thermal expansion of the at least one rotor coil **28** is biased toward the radial stud **32** in the sense that the portion of the at least one coil **28** closest to the radial stud **32** moves toward the radial stud **32**.

The thermal expansions thus generate stress forces in opposite axial orientations at different parts of the conductor **40**. As illustrated in FIGS. 5A, 5B, and 6, at

the point **45** at which the conductor **40** connects to the at least one rotor coil **28**, stress force is oriented toward the radial stud **32** in an axial direction relative to the lengthwise extent of rotor shaft **24**. Along an axial portion **41** of the conductor **40** extending from where the conductor **40** connects to radial stud **32**, stress force is oriented axially in the opposite direction away from the radial stud **32**. Were the conductor integrally formed, as, for example, conventional J-leads are, these forces would cause internal deformation in the conductor. As explained more fully below, however, the sectioned conductor **40** is formed of separate sectioned members that move substantially independently of each other while remaining electrically connected. The sectioned conductor **40** is able to provide a conductive path while substantially or entirely avoiding internal deformation due to stress forces by providing at least two sectioned members that move relative to each other while remaining electrically connected to one another.

An independent source of stress force on the sectioned conductor **40** stems from the centrifugal forces caused by the rotation of the rotor shaft **24** within the stator core **22**. The rotation thus causes centrifugally oriented forces on the at least one rotor coil **28** tending to pull the at least one rotor coil **28** away from the rotor shaft **24** in a radial direction relative to the rotor shaft **24**. Because the radial stud **32** is positioned within the rotor shaft **24**, the portion of the conductor **40** connected to the radial stud **32** tends to resist the centrifugal force resulting from rotation of the rotor shaft **24**. The portion of the sectioned conductor **40** connected to the at least one rotor coil **28**, however, experiences stress as

the at least one coil **28** tends to move away from the rotor shaft **24** in redial direction relative to the rotor shaft **24**. Hence, distinct portions of the sectioned conductor **40** experience stress forces directed radially as well as axially relative to the rotor shaft **24**. Moreover, mechanical vibrations that result from rotation of the rotor shaft **24** within the stator core **22** inevitably cause vibratory and other stress-inducing motions that are a separate source of stress forces.

As already alluded to above, in order to accommodate these stress forces while avoiding internal deformation, the sectioned conductor **40** preferably comprises at least two sectioned members. As perhaps best shown in FIGS. 5A, 5B, and 6, a first sectioned member **42** connects to the radial stud **32**, and a second sectioned member **44** connects to the at least one rotor coil **28**. The first sectioned member **42** preferably comprises an axial portion **41** connected to the radial stud **32** and a radial portion **43** extending outwardly from the axial portion **41** in a radial direction relative to the lengthwise extent of the rotor shaft **24**. A bore preferably extends into the second sectioned member **44** to thereby define a conductor channel **46** and to receive at least partially therein the radial portion **43** of the first sectioned member **42** (See FIG. 8). Although the radial portion **43** of the first sectioned member extends into the conductor channel **46**, it nevertheless remains substantially spaced apart from the surface of the conductor channel **46** to thereby avoid inhibiting movement of the second sectioned member **44** relative to the first sectioned member **42** in response to stress forces acting on the sectioned conductor **40**.

Although the first and second sectioned members **42**, **44** are substantially free from direct contact with each other, having at least a slight air gap between their respective surfaces so as to permit ready movement of the second sectioned member **44** relative to the first sectioned member **42**, the sectioned members remain electrically connected. The electrical connection, more specifically, is provided by at least one elastic conductor that is positioned to remain in electrically connected with both sections the second sectioned member **44** moves relative to the first sectioned member **42**. The electrical connection, moreover, can be maintained without fixedly connecting the elastic conductor to either section, as explained more fully below. Thus, the present invention provides a unique advantage over conventional devices in which an electrical connection between distinct sections is established only by fixedly connecting a conductor between the sections by brazing or soldering the conductor to each of the sections. The sustainable electrical connection provided by the at least one elastic conductor positioned between the first sectioned member **42** and the second sectioned member **44** allows the sectioned conductor **40** to serve as a conductive path between the at least one rotor coil **28** and radial stud **32** as the second sectioned member **44** moves relative to the first sectioned member **42**.

The first sectioned member **42** and the second sectioned member **44** can be electrically connected, for example, by positioning a separate conductor such as a flexible lead or a conductive coil spring between the first and second sectioned members **42**, **44** and connecting a first portion of the spring or lead to a surface portion of the first sectional member **42** and a second portion of the spring or lead to a surface portion of the second

sectioned member **44**. Preferably, as perhaps best illustrated in FIGS. 7-9, the sectioned member **42** and the second sectioned member **44** are electrically connected by at least one strip spring **50**. The preferred structure of the strip spring **50** is illustrated explicitly in FIG. 7. As illustrated, the strip spring comprises a substantially annular portion **52** and a pair of flanges **54** extending therefrom. The substantially annular portion **52** of the strip ring **50** can compress and stretch or otherwise contract and expand in response to various stress forces and then readily resume a predetermined shape in the absence of stress forces.

In the context of the present invention, the at least one strip spring **50** preferably is positioned at least partially within at least one notch **47** formed in the radial portion **43** of the first sectioned member **42**. The at least one notch **47** can be formed of different shapes and still serve adequately to secure the at least one strip spring **50** therein. For example, the notch can have a standard "V" shape. Alternatively, as specifically illustrated in FIG. 7, the notch can be rectangularly shaped or have other shapes as understood by those skilled in the art. As illustrated in FIG. 9, the at least one slip spring **50**, then, fits substantially snugly within the at least one notch **47** and is held in place by the pair of flanges **54** as the inherently elastic property of the partially compressed slip spring **50** causes each of the pair of flanges **54** to press against the right-angled portions of the notch surface. Thus, the strip spring **50** can be maintained in position without fixedly connecting the slip spring **50** to either the first or sectioned members **42**, **44** by brazing, soldering, or

otherwise effecting a fixed mechanical connection as with conventional devices. A pair of auxiliary notches can be formed, for example, within the right angle portions of the rectangularly shaped notch **47** to further secure therein the pair of flanges **54** substantially holding the slip spring **50** within the notch **47**.

As illustrated perhaps more clearly in FIG. 9, the apparatus **20** preferably comprises a plurality of slips springs **50, 55, 56, 57, 58, 59** secured in notches formed in the surface of the radial portion **43** of the first sectioned member **41**. Because the radial portion **43** of the first sectioned member **41** extends at least partially into the conductor channel **46** extending into the second sectioned member **44**, the space between the radial portion **43** of the first sectioned member **41** and the surface of the conductor channel **46** can be made sufficiently narrow so as to ensure that at least one of the plurality of the slip springs remains in surface contact with the surface of the conductor channel **46** even as the second sectioned member **44** moves relative to the first sectioned member **42**. Thus, as illustrated explicitly in FIGS.5A, 5B, and 9 the electrical connection between the first sectioned member **42** and the second sectioned member **44** is maintained as the latter moves relative to the former while contact between the surface of the conductor **46** and at least one of the plurality of slip springs **50, 55, 56, 57, 58, 59** is maintained. Movement can be axial radial, or any combination of movements.

Even greater degrees of freedom of movement are obtained if the conductor channel **46** extends entirely through a portion of the second sectioned member **44** to thereby define a groove formed in the second sectioned

member **44**. The width of the groove **44** is preferably greater than the corresponding cross sectional width of the radial portion **43** of the first sectioned member **42**. As illustrated perhaps most vividly in FIGS.5A and 5B, this permits the second sectioned member **44** to move even farther axially relative to the lengthwise extent of the rotor shaft **24**. The electrical connection between the first sectioned member **42** and the second sectioned member **44** is maintained provided that the surface of the second sectioned member **44** contacts at least a portion of at least one of the plurality of slip springs **50, 55, 56, 57, 58, 59** positioned in notches in the radial portion **43** of the first sectioned member **42**. As illustrated in FIGS.5A and 5B, the groove **46** thus permits the second sectioned member **44** to move almost completely past the radial portion **43** of the first sectioned member **42** and still remain in electrical contact with the first sectioned member **42**, thereby increasing the extent to which the second sectioned member **44** can effectively move axially relative to the lengthwise extent of the rotor shaft **24**.

The structural integrity of the apparatus **20** can be enhanced by a structural support **70** positioned to connect to the rotor shaft **24** and extending through the groove **46** in the second sectioned member **44** to connect to the radial portion **43** of the first sectioned member **42** (see FIGS.6 and 8). So positioned, the second sectioned member **44** is free to move axially and radially relative to the rotor shaft **24** while the support structure **70** extends through the groove **46** to preferably connect fixedly to the radial portion **43** of the first sectioned member **42**. The open groove **46** permits the second sectioned member to move

without obstruction from the support structure **70** as it extends into the open groove of the second sectioned member **44** of the sectioned conductor **40**. The structural support **70** can connect to the rotor shaft **24** at various points. Preferably, however, because the sectioned conductor can be positioned within in a slot formed in the rotor shaft **24**, the structural support **70** connects to a vertical portion of the slot extending upwardly from the rotor shaft **24**.

FIG.10 illustrates a second embodiment of the apparatus **80** having a sectioned conductor **100**. As illustrated, the first sectioned member **102** comprises a plurality of radially extending radial portions **103** and a second sectioned member **104** having formed therein a corresponding plurality of conductor channels extending completely through a portion of the surface of the second sectioned member **104** to define a plurality of grooves **106**. Moreover, a plurality of strip springs **110, 115, 116, 117, 118, 119** is positioned therein to permit the second sectioned member **104** to move relative to the first sectioned member **102** while remaining electrically connected thereto via the plurality of strip springs **110, 115, 116, 117, 118, 119**. At least one support structure can preferably be positioned on the rotor shaft **84** so as to extend through at least one of the plurality of grooves **106** and connect to at least one of the distinct radial portions extending therein.

FIG. 11 illustrates yet a third embodiment of the apparatus **140** in which the sectioned conductor **160** includes a third sectioned member **192** along with first and second sectioned members **162, 164**. The first sectioned member **162** is positioned to connect to the rotor shaft **144**

and preferably includes an axial portion **161** preferably having a plurality of slip springs positioned in notches formed in the surface of the axial portion **161**. The first sectioned member **162** further includes a radial portion **163**, also preferably having a plurality of slip springs positioned in notches formed in the surface of the radial portion **163**. The second sectioned member **164** is positioned to connect to at least one rotor coil **148** and preferably includes a bore **166** defining a second sectioned conductor channel extending into the second sectioned member **164** and positioned to at least partially receive therein the radial portion **163** of the first sectioned member **162**. As illustrated, the third sectioned member **192** is connected to the radial stud **152** extending into the rotor shaft **144**. The third sectioned member **192** preferably includes a third sectioned conductor channel **194** into which the axial portion **163** of the first sectioned member **162** extends.

The sectioned conductor **160**, so formed, permits the second and third sectioned members **164**, **192** of the sectioned conductor to move relative to the first sectioned member **162** in response to stress forces. The first, second, and third sectioned members remain electrically connected through contact maintained between the plurality of slip springs contacting surface portions of the second sectioned conductor **166** and the third sectioned conductor channel **194**. Accordingly, the sectioned conductor **160** provides a conductive path between the radial stud **152** and the at least one rotor coil **148** and is able to accommodate stress forces while substantially avoiding internal deformation.

FIGS. 1 through 11 also illustrate various method aspects of the present invention. The method aspects include a method for accommodating stress forces on an electrical connection while providing a conductive path between at least two spaced-apart electrical components within a generator. The method includes positioning a first portion **42** of a conductor **40** to electrically connect the first portion **42** to a first electrical component, positioning a second portion **44** of the conductor **40** to electrically connect the second portion to a second electrical component. The respective portions of the conductor **40** are specifically positioned to permit the second portion **44** to move relative to the first **42** in response to stress forces so as to thereby substantially avoid internal deformation of the conductor while also allowing the first and second portions **42, 44** to remain electrically connected to each other.

The method can further include electrically connecting the first portion **42** of the conductor **40** to the second portion **44** of the conductor **40** by positioning at least one electrically conductive slip spring **50** or other elastic conductor between the first portion **42** and the second portion **44** of the conductor **40** thereby providing a conductive path via the at least one slip spring **50** or other elastic conductor. In addition, the method can include reducing current-induced temperature effects in the conductor **40** by forming the first portion **42** of a material having a low ohmic resistance and forming the second portion **44** of a material also having a low ohmic resistance. Yet further, the method also can include providing enhanced structural support **70** to the conductor **40** by positioning a support structure **70** on a third

component of the generator and connecting the support structure to the first portion of the conductor.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.